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Water Quality Functions of Vegetative Buffer Systems: Evaluation Procedures and Enhancements

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Final Report

Research Joint Venture Agreement No. 28-JV7-951

between

USDA Forest Service Rocky Mountain Research Station
Research Work Unit RM-4551

and

University of Nebraska Department of Biological Systems Engineering

October 3, 2002

WATER QUALITY FUNCTIONS OF VEGETATIVE BUFFER SYSTEMS: EVALUATION PROCEDURES AND ENHANCEMENTS

Research Joint Venture No. 28-JV7-951, 1998, National Agroforestry Center
Final Report

Dean E. Eisenhauer and Thomas G. Franti

October 3, 2002

Introduction

Water quality improvement is one of the key functions of vegetative buffers. As water flows through buffers its quality is enhanced through sediment trapping, biochemical reduction of contaminants, and nutrient sequestration. Much of the previous research on buffers was conducted under small-scale controlled settings. The emphasis of this project was to conduct field and modeling studies at the scale where overland flow patterns are not controlled by the research plot boundaries. Without the use of artificial boundaries, water is allowed to flow naturally according to topography and micro-relief. Under natural flow conditions water can concentrate on the surface which may reduce contaminant removal in the buffer. The research objectives were to (1) develop field assessment tools for evaluation of the water quality function of buffer systems, (2)develop and/or modify computer simulation models which predict the impacts of buffers systems, and (3) apply the models to develop design guidelines and management procedures for enhancing the function of buffers for improving runoff water quality in the central U.S.

Field Procedures for Evaluation of Buffer Performance

Three projects were conducted as part of this objective. The first was an assessment of concentrated flow through riparian buffers. This study was conducted on four farms in southeastern Nebraska to develop a method for assessing the extent of concentrated flow in riparian buffers and for evaluating the impact that it has on sediment-trapping efficiency. Field methods consisted of mapping field runoff areas and their pathways through riparian buffers to streams. Mathematical relationships were developed from a model (VFSMOD) that estimates sediment-trapping efficiency from the ratio of buffer area to field runoff area. Among the farms surveyed, riparian buffers averaged 9 to 35 m. wide, and gross buffer area ranged from 1.5 to 7.2 ha, bu the effective buffer area that actually contracts runoff water was only 0.2 to 1.3 ha. Patterns of topography and micro-relief in fields and riparian zones prevented uniform distribution of field runoff across entire buffer areas. Using the mathematical relationships, it is estimated that riparian buffers at each of the four farms could potentially remove 99 %, 67 %, 59%, and 41 % of sediment from field runoff if the runoff is uniformly distributed over the entire gross buffer area. However, because of non-uniform distribution, it is estimated that only 43%,

15%, 23%, and 34% , respectively would actually be removed. The results indicate that concentrated flow through riparian buffers can be substantial and may greatly limit filtering effectiveness in this region. The field procedure that we developed can be used to assess the effect of the flow concentration on buffer performance.

A second component of this objective was to develop an overland flow sampler for evaluation of vegetative buffer performance in uncontrolled flow settings. We developed a sampler with a 0.3 m wide inlet that has the capacity to sample a flow rate of 1.3 L/s and a runoff volume of about 20 000 L. The sampler was tested in the laboratory, in field experiments, and using a simulation model. Overall the sampler split ratio is 2180 meaning that if 2180 L of water flowed through the sampler inlet, 1 L of sample would be collected for measurement and analysis. The split ratio was essentially constant when the flow rate ranged from 0.1 to 1.0 L/s. Computer simulations of overland flow using MIKE SHE, a distributed hydrologic simulation model, indicate that the sampler does not cause significant convergence or divergence of flow when sampling at the downstream edge of the buffer. Because of the higher roughness in the buffer relative to the row-cropped contributing watershed, relatively long wing walls are needed to avoid flow convergence when sampling at the leading edge of the buffer. The required length of the wingwall is dependent on land slope, flow rate, and the hydraulic roughness of the buffer. The runoff volume and runoff hydrographs that were derived from the sampler agreed well with the measurements taken with flow measurement flumes. Equations were developed to help interpret the data collected with the sampler. The sampler has proven to be a useful tool in our buffer research projects where flow into and through buffers is not controlled by artificial boundaries.

The third component of this project was a field study of the direction and concentration of surface water flow in a vegetative buffer. This project was conducted at the Clear Creek site near Osceola, Nebraska. The study was performed to assess the spatial variation of surface water flow through a vegetative buffer and, in particular, to what extent the water flow concentrates. The topography of two areas of an existing vegetative buffer was surveyed in detail. Two surveys were conducted; one with 6 cm resolution (low resolution) and one with approximately 3 cm resolution (high resolution). The runoff through the filter from three surface irrigation events was monitored. The water outflow rate was monitored at one location in each area and inflow rate was monitored at multiple locations. Two dye tracer studies were performed to map the path of water flow. For three of the five experiments, the study showed the maximum rate of flow out of the filter was greater than the average inflow rate and the average volumetric inflow per unit width was less than the volumetric outflow rate per unit of width, indicating flow concentration. The tracer study showed that the water flow generally followed the topography mapped in the high resolution survey. Identification of watershed facets within the buffer supported the flow concentration hypothesis.

Computer Simulation Modeling of Buffers Systems

This component of the research consisted of two topics; modeling two-dimensional overland flow in vegetative filters and modeling the effect of topographic accuracy and micro-relief on buffer performance. The modeling of two-dimensional overland flow in vegetative buffers considers the variation in micro-relief, infiltration, and surface roughness. Simulation of the flow processes was performed using the physically based, distributed model, MIKE SHE. Simulations were performed with constant and variable topography and constant and variable soil hydraulic properties. Model input parameters were obtained at the Clear Creek research site (topographic variation was discussed in the previous section). Soil hydraulic properties were gathered at the site to represent the spatial variation in infiltration. Both the variable topography and variable soil hydraulic properties influenced the outflow hydrographs from the buffer. The outflow rate at the downstream edge of the vegetative buffer was not uniformly distributed indicating flow convergence and divergence within the buffer. Predicting the implications of the non-uniform distribution of outflow on sediment trapping is a follow-up study that is currently being conducted.

In the second modeling study, the effect of topographic data accuracy on predicted runoff patterns in two stream valley sites was investigated. The relative error in slope aspect angle, caused by inaccurate topographic data, was found to be inversely related to land slope. High topographic accuracy was found to be vital to accurate prediction of runoff patterns at sites with low slopes.

A discriminant analysis method (Souchere et al., 1998) that accounts for the effect of micro-relief on runoff direction was also evaluated. A field experiment demonstrated that this method improves predictions of runoff direction, with runoff direction being correctly predicted in 80% of the observations. The discriminant analysis method was used with topographic data sources having accuracies of ± 1.5 m, ± 0.3 m, and ± 0.15 m to predict the catchment area for an existing riparian buffer at the Rogers Memorial Research Farm (Rogers Farm), near Lincoln, NE. It was concluded that runoff patterns were most sensitive to micro-relief when low accuracy topography, ± 1.5 m, was used. However, prediction of runoff flow paths and flow entry locations into the buffers was more sensitive to topographic data accuracy.

The Soil and Water Assessment Tool (SWAT) was used to predict runoff and soil loss at Rogers Farm under conditions generated by three topographic data sources and the discriminant analysis method. The Riparian Ecosystem Management Model (REMM) was then used to predict the impact of an existing riparian buffer on sediment delivery to the stream. This analysis showed that topographic accuracy and micro-relief consideration affected predictions of buffer performance. Trapping efficiencies ranged from 19% to 70% depending on topographic data source and micro-relief. The three topographic data sources and the discriminant analysis method were also used in a planning mode to select buffer location and dimensions at the same

site. Topographic accuracy and micro-relief considerably influenced the location, dimensions and predicted performance of planned buffers.

Application of Models for Developing Design Guidelines

The model VFSMOD was used to investigate the effect of varying watershed characteristics and buffer dimensions on the sediment trapping efficiency of vegetative filters. We developed relationships that estimate sediment trapping efficiency from the ratio of filter area and field area (buffer area ratio). The buffer area ratio proved to be a useful tool for predicting buffer performance for a watershed with a given soil texture and land slope. The development of the buffer area ratio approach should lead to improved design of buffers and improved methods for evaluating a buffers potential performance.

Products of Research Joint Venture Agreement

Agreement #: 28-JV7-951
Cooperators: Dean Eisenhauer and Tom Franti, University of Nebraska, Department of Biological Systems Engineering
Period: August 15, 1997- August 15, 2002 (5 years)
FS Costs: $50,000

Administrative Products
Agreement, 8/15/97
Work Plan, 6/11/97
Progress Reports 7/1/98, 12/1/99, 12/1/00,12/1/01

Research Sites Established
Riparian Assessment (four farms in SE Nebraska)
Clear Creek Watershed and Buffer Sites (near Osceola)
Rogers Farm Riparian Forest Buffer (near Lincoln)
Rogers Farm Stiffgrass Hedges (near Lincoln)

Personnel Supported
Dawit Zerihun, Postdoc
Daneal Fekersillassie, Postdoc
Alan Boldt, Research Engineer
Carla McCullough, Research Engineer
Brandon Strahm, Student Assistant
Lisa Stahr, Student Assistant
Shelbie Pridie, Student Assistant
Matthew Helmers, Ph.D. student
Jason Brothers, M.Sc. student
Liz Hostetter, Undergraduate honors student
Kelly Kinneson, Undergraduate honors student

Leveraged Funds Obtained

Nebraska Corn Development, Utilization and Marketing Board. July 1997. "Development and Testing of Field Techniques for Estimating the Effectiveness of Grass Buffer Strips." D. Eisenhauer, M. Dosskey, T. Franti, and K. Hoagland. $21,000 for 1 yr. Approved.

USDA Agricultural Experiment Station (Hatch) Project. 1998. Hydrologic Modeling and Engineering for Enhancement of Vegetative Riparian Buffers. D. Eisenhauer. $79,000 for 5 yrs. Approved.

UNL Channing B. and Katherine W. Baker Fund. 1999. "Hydrologic modeling for enhanced design and management of vegetative buffers." D. Eisenhauer (Dosskey as collaborator). Approved.

North Central Region Agricultural Experiment Stations project. 1999. "Integrated biophysical functions of riparian systems with management practices and policies." D. Eisenhauer et al. (Dosskey as collaborator). $10,000 for 3 yrs. Approved.

UNL Agricultural Research Division Interdisciplinary Grant. 2000. "Development and testing of field techniques for estimating the effectiveness of vegetative filter strips." D. Eisenhauer, M. Dosskey, T. Franti, K. Hoagland, and D. Marx. $40,000 for 2 yrs. Approved.

USDA CSREES Integrated Research, Education & Extension Competitive Grants Program, Water Quality. May 2001. "Control of Agrichemical Loading to Streams Using Grassed Buffers in Great Plains Watersheds. D. Eisenhauer, R. Spalding, T. Franti, D. Snow, and M. Dosskey. $565,000 for 3 yrs. Approved.

Other Project Proposals Developed

USEPA/NDEQ Section 319 Proposal. 1998. "Impact of Vegetative Buffer Strips on Pesticide, Nitrogen, and Sediment Loading to Clear Creek and Adjacent Ground Water." R. Spalding, D. Eisenhauer, T. Franti, K. Hoagland, and M. Dosskey. $273,840 for 2 yrs (not funded)

Nebraska Corn Development, Utilization and Marketing Board. 1998. "Development and Testing of Field Techniques for Estimating the Effectiveness of Grass Buffer Strips." D. Eisenhauer, M. Dosskey, T. Franti, and K. Hoagland. $22,000 for 1 yr. (not funded)

USGS/NIWR Water Resources National Competitive Grants Application. 1999. "National site for evaluation of the impact of vegetative buffer strips on agricultural loading to a Great Plains watershed." Spalding et al. (Dosskey as collaborator) $248,000 for 3 yrs. (not funded)

USDA Initiative for Future Agriculture and Food Systems. 2000. "Great Plans riparian buffers for water quality and on-farm income.' Franti et al. (Dosskey as collaborator) $999,000 for 4 yrs. (not funded).

USDA Initiative for Future Agriculture and Food Systems. 2000. Consortium for Buffer Ecosystem Technology. Lowrance et al. (Dosskey as collaborator with PI Eisenhauer at UNL). UNL subcontract request $328,000 for 4 yrs. (not funded).

USDA CSREES Integrated Research, Education & Extension Competitive Grants Program. 2000. "Adoption of riparian buffers to enhance water quality and on-farm income." Franti et al. (Dosskey as collaborator) $592,000 for 3 yrs. (not funded).

Nebraska Environmental Trust. 2000. "Monitoring impact of grassed buffer strips on water quality." Spalding et al. (Dosskey as collaborator) $199,000 for 3 yrs. (not funded).

USDA National Research Initiative Competitive Grants Program. November 2000. "Evaluating the performance of farm-scale riparian buffers in the Great Plains". D. Eisenhauer, R. Spalding, T. Franti, D. Snow, and M. Dosskey. $350,000 for 3 yrs. (not funded).

Publications

Dosskey, M.G., M.J. Helmers, D.E. Eisenhauer, T.G. Franti, and K.D. Hoagland. (in press). Assessment of concentrated flow through riparian buffers. Journal of Soil and Water Conservation.

Eisenhauer, D. M. Dosskey, M. Helmers, J. Brothers, and T. Franti. 2002. Influence of topography on sediment trapping in grass buffers. Center for Grassland Studies 8(No. 3, Summer):1, 3.

Brothers, J.M. 2002. Riparian Buffer Planning and Assessment Considering Topographic Accuracy and Microrelief. Master of Science Thesis, University of Nebraska, Lincoln, NE.

Hostetter, L. 2002. Role of infiltration on contaminant reduction in buffers. Honors Thesis, University of Nebraska, Department of Biological Systems Engineering, Lincoln, NE.

Kinneson, K. 2002. Mini overland flow sampler research for the evaluation of vegetative buffer strips. Honors thesis. University of Nebraska, Department of Biological Systems Engineering, Lincoln, NE.

Helmers, M.J., D.E. Eisenhauer, T.G. Franti, and M.G. Dosskey. 2002. Modeling of two-dimensional overland flow in a vegetative filter. Paper No. 02-2165. American Society of Agricultural Engineers, St. Joseph, MI.

Helmers, M.J., D.E. Eisenhauer, M.G. Dosskey, and T.G. Franti. 2002. Modeling vegetative filter performance with VFSMOD. Paper No. MC02-308. American Society of Agricultural Engineers, St. Joseph, MI.

Eisenhauer, D., M. Helmers, J. Brothers, M. Dosskey, T. Franti, A. Boldt, B. Strahm. 2002. An overland flow sampler for use in vegetative filters. Paper No. 02-2050. American Society of Agricultural Engineers, St. Joseph, MI.

Brothers, J.M., D.E. Eisenhauer, M.J. Helmers, M.G. Dosskey, and T. G. Franti. 2001. Modeling vegetative buffer performance considering topographic data accuracy. Paper No. 01-2125. American Society of Agricultural Engineers, St. Joseph, MI.

Helmers, M.J., D.E. Eisenhauer, J.M. Brothers, M.G. Dosskey, and T.G. Franti. 2001. Direction and concentration of surface water flow in a vegetative filter system. Paper No. 01-2170. American Society of Agricultural Engineers, St. Joseph, MI.

Dosskey, M.G., D.E. Eisenhauer, M. Helmers, T.G. Franti, T. Houston, K.D. Hoagland. 2001. Field assessment of concentrated flow patterns of surface runoff through riparian buffers. Presentation Abstract. p. 313 in W. Schroeder and J. Kort (eds.) Temperate Agroforestry: Adaptive and Mitigative Roles in A Changing Physical and Socio-Economic Climate. Proceedings of the 7th Biennial Conference on Agroforestry in North America and 6th Annual Conference of the Plains and Prairie Forestry Association. August 12-15, 2001, Regina, SK, Canada.

Dosskey, M.G., D.E. Eisenhauer, M. Helmers, T.G. Franti, T. Houston, K.D. Hoagland. 2000. Field assessment of concentrated flow patterns of surface runoff through riparian buffers. p. 380 In Abstracts, Annual Meetings of the American Society of Agronomy, November 5-9, 2000, Minneapolis, MN.

Presentations

Eisenhauer, D., M. Helmers, J. Brothers, M. Dosskey, T. Franti, A. Boldt, B. Strahm. 2002. An overland flow sampler for use in vegetative filters. Presented at the Annual International Meeting, American Society of Agricultural Engineers, July 28-31, 2002, Chicago, IL.

Helmers, M.J., D.E. Eisenhauer, M.G. Dosskey, and T.G. Franti. 2002. Modeling vegetative filter performance with VFSMOD. Presented at the Annual Mid-Central Meeting, American Society of Agricultural Engineers, April 12-13, 2002, St. Joseph, MO.

Helmers, M.J., D.E. Eisenhauer, T.G. Franti, and M.G. Dosskey. 2002. Modeling of two-dimensional overland flow in a vegetative filter. Presented at the Annual International Meeting, American Society of Agricultural Engineers, July 28-31, 2002, Chicago, IL.

Helmers, M.J., D.E. Eisenhauer, J.M. Brothers, M.G. Dosskey, and T.G. Franti. 2001. Direction and concentration of surface water flow in a vegetative filter system. Presented at the Annual International Meeting, American Society of Agricultural Engineers, July 30-August 1, 2001, Sacramento, CA.

Brothers, J.M., D.E. Eisenhauer, M.J. Helmers, M.G. Dosskey, and T. G. Franti. 2001. Modeling vegetative buffer performance considering topographic data accuracy. Presented at the Annual International Meeting, American Society of Agricultural Engineers, July 30-August 1, 2001, Sacramento, CA.

Dosskey, M.G., D.E. Eisenhauer, M. Helmers, T.G. Franti, T. Houston, K.D. Hoagland. 2001. Field assessment of concentrated flow patterns of surface runoff through riparian buffers. Presented at the UNL/IANR Faculty Research Information Meeting, March 12, 2001, Lincoln, NE.

Dosskey, M.G., D.E. Eisenhauer, M. Helmers, T.G. Franti, T. Houston, K.D. Hoagland. 2001. Field assessment of concentrated flow patterns of surface runoff through riparian buffers. Presented at the combined meetings 7th Biennial Conference on Agroforestry in North America and the 6th Annual Conference of the Plains and Prairie Forestry Association. August 12-15, 2001, Regina, SK, Canada.

Dosskey, M.G., D.E. Eisenhauer, M. Helmers, T.G. Franti, T. Houston, K.D. Hoagland. 2000. Field assessment of concentrated flow patterns of surface runoff through riparian buffers. Presented at the Annual Meetings of the American Society of Agronomy, November 5-9, 2000, Minneapolis, MN.

Eisenhauer, D. 1999. Testing improved sampler designs for surface runoff through buffers. Presented to scientists of the USDA-ARS Southeast Watershed Research Lab, March 24, 1999, Tifton GA.

Eisenhauer, D., T. Franti, M. Dosskey, and K Hoagland. 1997. Field assessment of surface runoff patterns into riparian areas. Presented at the Vegetative Filter Strip and Riparian Buffer Research Symposium, Sponsored by the Nebraska Corn Growers Association and the University of Nebraska, December 17, 1997, Omaha, NE.

Other Products

Zerihun, D., D.E. Eisenhauer, and M. Dosskey. 1999. Vegetative Buffers as Nonpoint Source Pollutant Sinks: Modeling and Design, A Review. (unpublished literature review of existing models to provide foundation for subsequent modeling projects and project proposals.)

Future Products Expected

Peer-reviewed manuscripts from:

- Matt Helmers dissertation research
- Jason Brothers thesis research
- Overland flow sampler develoment
- Dimensional analysis research
- Riparian assessment data set (whole-farm filtering)